# Z-Scan : A Tool to Explore Third Order Optical Nonlinearity

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Last Modified on: September 2, 2017

## Contents



**Z-Scan is a simple and powerful tool, used to explore the third order nonlinear optical properties of materials. The main advantage is sample of any form, such as crystal, powder, thin**

**film or liquid can be studied using this technique. This handout breifly describing the z-scan method with its significance. Starting with an introduction to nonlinear optics and its applications, we breifly explain the techniques available to characterize third order optical nonlinearity with a special emphasize to z-scan. Then, the basics, theory, instrumentation and different configurations are discussed. In addition, physics behind the z-scan curves are also provided with some examples and prototypes.**

# 1 Introduction

Z-scan is one of the very famous tools available to analyse third order nonlinear optical properties of materials. The objective of this review is to provide the basics and physics behind the z-scan method. But prior to that, a short review on nonlinear optics and its applications is provided for better understanding. Nonlinear optics can be better understood by differentiate it from linear optics. For that, let us consider a dielectric medium placed in an electric field. It can be linearly polarized, if the medium does not have a transition (or absorption) at the frequency of the field. Each constituent molecule acts as a dipole, with a dipole moment $P_i$. The net dipole moment per unit volume is given by

$$P = \sum_i P_i \tag{1}$$

The orienting effect of the external field on the molecular dipoles depend both the properties of the medium and the field strength. Thus, we can write

$$P = \epsilon_0 \chi E \tag{2}$$

where, $\chi$ is called the linear polarizibility or dielectric susceptibility of the medium. This relation is valid for the field strength of conventional sources. The quantity $\chi$ is a constant only in the sense of being independent of $E$; its magnitude is a function of the frequency. With sufficiently intense laser radiation the above relation does not hold good and has to be generalized as

$$P = \epsilon_0(\chi^{(1)}E + \chi^{(2)}E^2 + \chi^{(3)}E^3) \tag{3}$$

where $\chi^{(1)}$ is the same as $\chi$. The coefficients $\chi^{(2)}$, $\chi^{(3)}$..., define the degree of nonlinearity and are known as nonlinear susceptibilities. If the field is low, as in the case of ordinary light sources, only the first term of the above equation can be retained. It is for this reason that the prelaser optics is known as linear optics. Higher the value of the electric field, more significant become the higher order terms. It may be noted that optical characteristics of a medium, such as dielectric permittivity, refractive index, etc., which depend upon susceptibility, also become functions of the field strength E, if it is sufficiently high. The polarization of the medium described by a nonlinear relation in eqn. 3 is called as a nonlinear medium. Suppose now, the field incident on the medium has the form

$$E = E_0 \cos(\omega t) \tag{4}$$

Substituting this in eqn. 3, we have

$$\begin{aligned} P = \epsilon_0(\chi^{(1)}E_0\cos(\omega t) + \chi^{(2)}E^2\cos(\omega t) \\ +\chi^{(3)}E^3\cos(\omega t)) \end{aligned} \tag{5}$$

The first term is related to the external polarization and is called as the first or fundamental harmonic of polarization. The second oscillates at frequency $2\omega$ and is called as second harmonic of polarization, the third oscillates at frequency $3\omega$ and is called as third harmonic of polarization, and so on.

# 2 Types of Optical Nonlinearity

## 2.1 Second Harmonic Generation

The polarization oscillating at frequency $2\omega$ radiates an electromagnetic wave of the same frequency, which propagates with the same velocity as that of the incident wave. The wave, thus produced has the same characteristics of directionality and monochromacity as the incident wave and is emitted in the same direction. This phenomenon is known as the Second Harmonic

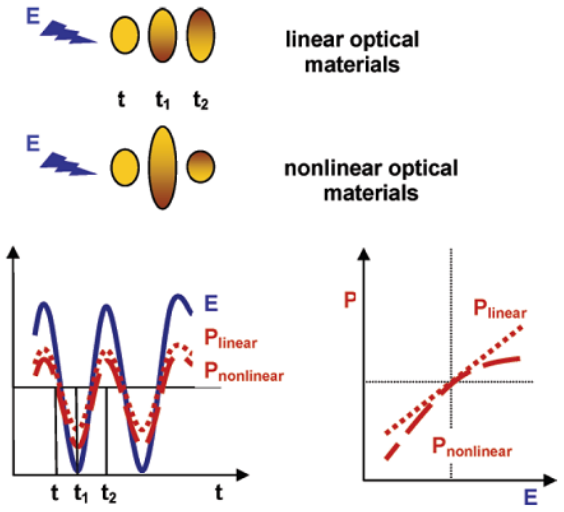


**Figure 1:** *Linear and nonlinear polarizability comparison*

Generation (SHG). In most crystalline materials, the nonlinear polarizability $\chi^2$ depends on the direction of propagation, polarization of the electric field and the orientation of the optic axis of the crystal. Since in such crystalline materials the vectors P and E are not necessarily parallel and the coefficients $\chi$ must be treated as tensors. The second order polarization, therefore, may be represented by the relation of the type

$$P_i^{(2)} = \epsilon_0 \sum_{i,j} \chi_{ijk}^{(2)} E_j E_k \tag{6}$$

where i, j, k represent the coordinates x, y, z. Most of the coefficients $\chi_{ijk}^{(2)}$, however, are usually zero and we have to deal only with one or two components. It must be mentioned here that second harmonic generation cannot occur in an isotropic medium such as liquids or gases nor in centrosymmetric crystals. Only the crystals lack inversion symmetry exhibit SHG.

## 2.2 Applications of Second Order Nonlinearity

Second order nonlinear effects are involved in numerous applications especially to obtain laser sources at wavelength that are not available with "standard" sources. Parametric amplification leads to parametric gain for the signal field. Using parametric material in a resonant cavity (at least for signal frequency), a parametric oscillator can be obtained. This kind of source is equivalent to a laser source in which stimulated emission is replaced by parametric emission. Parametric sources can be widely spectrally tunable by changing the phase matching conditions with an exterior parameter like temperature or light incident angle on the nonlinear crystal. There is also a quadratic phenomenon which is the parametric equivalent to spontaneous emission: parametric fluorescence. This effect consists of the spontaneous creation in nonlinear crystal of two photons with frequency $\omega_1$ and $\omega_2$ from one photon at $\omega_3$. This phenomenon can be used in light sources for quantum cryptography protocols.

## 2.3 Third Harmonic Generation

As we stated earlier, in the case of centrosymmetric materials, the eqn. 3 will lack terms in even powers of E and it will reduced to

$$P = \epsilon_0(\chi^{(1)}E + \chi^{(3)}E^3 + ...) \tag{7}$$

That is, third harmonic generation (THG) is, therefore, possible even in crystals / molecules that exhibit inversion symmetry. The development of Q-switched lasers had made it possible to generate third harmonic crystals. However, the energy conversion efficiency in such cases is very low. For example, in calcite the maximum energy conversion efficiency in the third harmonic was 0.01%.

## 2.4 Applications of Third Order Nonlinearity

Among all the nonlinear process, the optical THG is certainly used as one of the most important mechanism for applications. Indeed, this effect is involved in a great number of phenomena such as:

1. **Self-focusing and self-defocusing** this comes from nonlinear refractive index variation in space.

2. **Self-phase modulation**, it is presently used in optical fiber transmission systems to compensate chromatic dispersion of silica in order to propagate temporal solutions.

3. **Four wave mixing** degenerated in frequency. Two powerful pump waves at the frequency of $\omega$ interfere to create a nonlinear refractive index grating. A third wave of weak intensity is then partially diffracted by the grating which gives birth to the fourth wave.

# 3 Tools to Study THG

A number of techniques are available to measure third-order susceptibilities. They are associated with different nonlinear phenomena and some of the famous methods are listed below.

1. Third-Harmonic Generation
2. Electric-Field-Induced Second-Harmonic Generation (EFISHG)
3. Degenerate Four-Wave Mixing (DFWM)
4. Z-Scan
5. Optical Kerr Gate (OKG)

## 3.1 Third-Harmonic Generation

Third-Harmonic Generation or frequency tripling is a process of nonlinear frequency conversion where the resulting optical frequency is three times that of the input laser beam. In principle, this can be achieved with a $\chi^{(3)}$ nonlinearity for direct third-harmonic generation, but this is difficult due to the small $\chi^{(3)}$ nonlinearity of optical media and phase-matching constraints (except for tripling in gases). Therefore, frequency tripling is usually realized as a cascaded process, beginning with frequency doubling of the input beam and subsequent sum frequency generation of both waves, with both processes being based on nonlinear crystal materials with a $\chi^{(2)}$ nonlinearity. THG experiments is much more complex in practice. Since all media (including air and the glass walls of the cell) present a third-order nonlinear effect, one has to be extremely careful in the analysis of third-harmonic data.

## 3.2 Electric-Field-Induced Second-Harmonic Generation (EFISHG)

Electric-Field-Induced Second-Harmonic Generation is a third-order technique gives second-harmonic generation which can be used to estimate the third order susceptibility. The principle is by applying an electric field, the center of inversion of a gas or liquid is broken allowing bulk second harmonic generation. But this is applicable only in the case of dipolar molecules where orientational coupling to the static field is allowed. In addition, the presence of a strong static field limits the technique to non-charged species.

## 3.3 Degenerate Four-Wave Mixing (DFWM)

In a degenerate four-wave mixing process, there is an interaction between three beams to generate a fourth beam of the same frequency. The degenerate four-wave mixing process derives its contributions from both the real and the imaginary parts of $\chi^{(3)}$. It is a convenient method for measuring both electronic and dynamic nonlinearities and for obtaining their time response. The technique is highly sensitive because the signal is a phase-matched nonlinear response. The main disadvantage is that picosecond pulses and a good control over the experimental conditions are required.

## 3.4 Optical Kerr Gate (OKG)

This effect is the optically-induced birefringence caused by a nonlinear phase shift. Evolution of the birefringence and hence the response time of $\chi^{(3)}$ can be probed. There are various mechanisms (electronic deformation, molecular reorientation, molecular libration, molecular redistribution, electrostriction, thermal change) that are responsible for the change of nonlinear refraction index in the OKG and each mechanism has different strengths and response times.

# 4 Z-Scan: Basics

Among the techniques mentioned above, z-scan is rather a simple single-beam method based on self-focusing effect caused by third-order nonlinearity. It is called self-action because the nonlinear polarization induced by the incident beam changes the propagation or other properties of the same incident beam. This effect does not give any time response information. Even weakly absorbing samples and a long interaction length provide large refractive index changes derived from thermal effects.

## 4.1 Historic Survey

Presently, materials with self-focusing effect are often consider for developing optical limiters (OPL). But historically optical limiters were fabricated before the invention of z-scan technique. In fact, z-scan method is derived from the experimental setup of optical limiters to estimate $\chi^{(3)}$. The first of these techniques was developed by Soileau et al. in 1983. Frazier et al. measured in 1987 the nonlinearity of palladium polyyne films with OPL. The third-order nonlinearity of ferrocene in the molten form and in solution was investigated with the same technique in 1988 by Winter, Oliver, and Rush. The optical limiting behavior of semiconductors was studied by Van Stryland and co-workers and the dispersion and two-photon absorption characteristics of these materials by Sheik-Bahae et al. They also established z-scan and measured the $\chi^{(3)}$ values of $CS_2$ and $BaF_2$ in 1990. In 1991, Soileau et al. demonstrated the z-scan technique for a solution of chloroaluminum phthalocyanine at 532 nm. In the same year, Perry et al. also investigated the excited-state absorption and optical limiting behavior of metallophthalocyanines with the z-scan. The resonant third-order nonlinearity of polythiophene thin films was investigated by the z-scan in 1992; the results indicated that the negative nonlinearity at 532 nm is resonantly enhanced (at the one-photon transition) and is associated to the saturation of the absorption. Sheik-Bahae et al. in 1992 developed a two-color z-scan method to measure the nondegenerate nonlinearities at frequency $\omega_p$ in the presence of light at frequency $\omega_e$. There after many materials in different forms are studied by z-scan method using either single or dual beam technique.

## 4.2 Theory

The intensity-dependent refractive index responsible for self-action (self-focusing, self-defocusing, and self-phase modulation) is given by

$$n(\lambda) = n_0(\lambda) + n_2(\lambda)I \tag{8}$$

where I denotes the intensity of the wave and $n_0$, the linear refractive index and $n_2$ is the nonlinear refractive index coefficient. Self-focusing occurs as a combined effect of a positive $n_2$ and a spatial variation of the laser beam intensity (more intense in the center than at the edges). This results in a larger refractive index of the nonlinear medium in the center of the beam. The medium acts as a positive lens and focuses the beam. Self-defocusing happens when $n_2$ is negative and the nonlinear polarization creates a negative lens which defocuses the beam.

## 4.3 Experimental Technique

In this technique, the sample under investigation is moved along the tightly focused Gaussian laser beam. The intensity of the laser beam changes as the sample is moved. This is because the sample experiences different intensities, depending on the position of the sample relative to focus (z=0). The power transmitted through the sample is measured by translating the sample along the z-direction through the beam waist of a focused beam and hence the name z-scan. In our experiments a continuous wave diode laser operating at 650 nm was used. Figure 2 shows the schematic of z-scan experimental set up used for the experiments. The laser beam was focused using a 15 cm focal length lens. The beam waist is found to be 36.78 $\mu m$ which can be calculated using the formula, $\omega_0 = 1.22\lambda f/d$ where $\lambda$ is the wavelength of laser, f is the focal length of the lens and d is the diameter of laser beam. Another parameter known as Rayleigh length or Rayleigh range is defined as, the distance along the propagation direction of a laser beam from the waist to the place where the area of cross section is doubled. It is important to keep the thickness of the sample much

lesser than that of the Rayleigh length and it can be calculated using the formula, $z = 2\pi\omega_0^2/\lambda$ The two important parameters required to determine the $\chi^{(3)}$ is nonlinear refractive index $n_2$ and nonlinear absorptive coefficient $\beta$. The nonlinear refractive index $n_2$ can be determined by performing closed aperture z-scan experiments and similarly the nonlinear absorptive coefficient $\beta$, can be determined by performing open aperture z-scan experiments. A brief description on the open and closed aperture z-scan is given below.

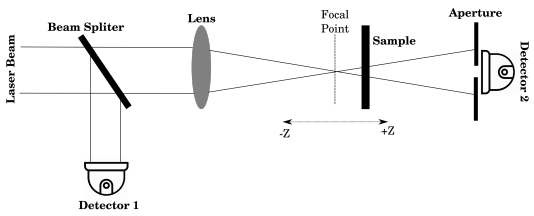


**Figure 2:** *Schematic z-scan experimental set up*

### 4.3.1 Open aperture z-scan

When a Gaussian laser beam is incident on a nonlinear medium, it induces profound changes in the optical properties of the medium. Nonlinear absorption refers to the change in transmittance of the medium as a function of intensity or fluence. By performing the open aperture z-scan experiment, the nonlinear absorption coefficient $\beta$ of the nonlinear medium can be computed. In open aperture z-scan experiments, aperture (S = 1) is insensitive to nonlinear refraction. That is, there won't be any aperture in front of detector 2. The z-scan traces obtained with no aperture is expected to be symmetric with respect to the focus (z=0) where the transmittance is minimum. In this experiment, the sample is made to traverse from one end of the farfield to the other end through the focus (z = 0). At the farfield, the intensity is low and hence linear absorption occurs. In other words, the intensity is not sufficient to induce any nonlinear absorption in the farfield region. A graph of normalized transmittance along y-axis and the sample position along x-axis is plotted.

When the sample approach focus, the measured transmittance in detector either decreases or increases, forming a valley or peak at the focus. The process in which the measured transmittance forms a valley at the focus is known as reverse saturable absorption and is shown in Figure 3(a). The process in which the measured transmittance forms a peak at the focus is known as saturable absorption and is shown in Figure 3(b). The saturable absorption is also known as negative type of absorption nonlinearity and reverse saturable absorption is known as positive type of absorption nonlinearity. Using the open aperture z-scan traces, the coefficient of nonlinear absorption is determined and it is related to the imaginary part of the thirdorder nonlinear susceptibility $\chi^{(3)}$.

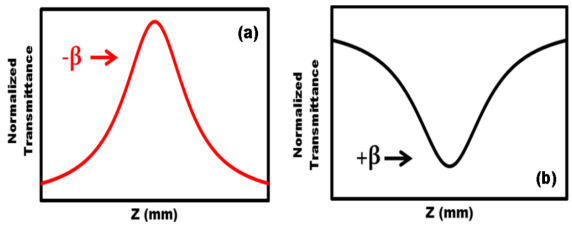


**Figure 3:** *Open aperture z-scan traces (a) saturable absorption and (b) reverse saturable absorption curves*

### 4.3.2 Closed aperture z-scan

Closed aperture z-scan experiment is performed to measure the nonlinear index of refraction $n_2$. Nonlinear refraction is the phenomenon where the refractive index of medium varies at high intensity or fluence. In closed aperture z-scan experiment, an aperture is placed in front of detector 2. When a Gaussian laser beam is made to pass through the material medium, it acts like an intensity dependent lens. Along the beam path, the effective focal length of medium changes due to the change in input intensity. This results in the intensity distribution at the far field aperture. The amount of energy transmitting through the aperture depends on the sample location on the z-axis and on the sign of nonlinear refractive index $n_2$. The prefocal transmittance maximum (peak) followed by post focal transmittance minimum (valley) behaviour is the characteristic of a material with a negative nonlinear refractive index. On the other hand, a valley followed by a peak is the characteristic of a positive nonlinear refractive index as shown in Figure 4. For ideal

case, the nonlinear absorption is often neglected. But in most practical situations, the measured transmission will be more complex that is nonlinear refraction will occur in conjunction with nonlinear absorption. The sensitivity of nonlinear refraction is entirely due to the aperture, and removal of aperture completely eliminates the effect. Generally saturable absorption and reverse saturable absorption will modify the peak and valley characteristics. Saturable absorption enhances the peak and suppresses the valley, whereas reverse saturable absorption enhances the valley and suppresses the peak. This can be deduced by performing open aperture z-scan experiment. To extract pure nonlinear refraction traces, closed aperture data must be divided with the open aperture data.

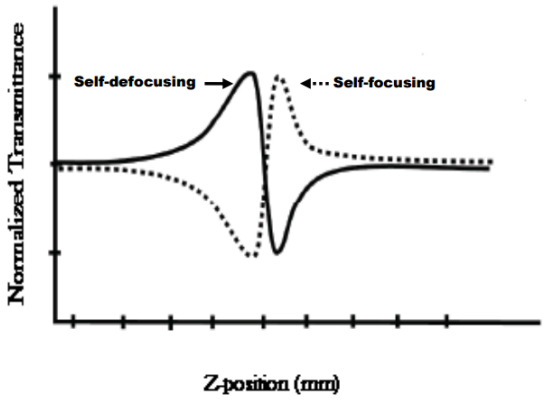


**Figure 4:** *Closed aperture z-scan transmittance curve depicting self-focusing and defocusing nature*

## 4.4 Merits and demerits of z-scan

**Merits**

- It is simple and very sensitive technique to measure the nonlinear refraction and absorption coefficients.
- It has no difficult alignment other than beam aligning on the aperture.
- It can be used to determined sign and magnitude of $n_2$.
- Data analysis is quick and simple.
- It can determine both real and imaginary parts of $\chi^{(3)}$.
- Z-scan can also be modified to study nonlinearities of higher order contributions.

**Demerits**

- It requires a high quality Gaussian TEM00 beam for absolute measurements.
- The analysis must be different if the beam is non-Gaussian.
- Sample distortions, tilting of sample during translation, can cause the beam to walk off the far field aperture.
- The introduction of second beam of different frequency requires careful alignment of the two beams.

# 5 Physics behind the curves

## 5.1 Saturable and reverse saturable absorption

Materials with saturable absorption absorb the greatest fraction of the incident radiant power when the input fluence (total delivered energy per unit area) is low, with the absorption diminishing as the fluence increases. Physically, this occurs because the absorption cross-section for the ground state is greater than the absorption cross-section(s) for the excited state(s). The observed decrease in absorption with increasing fluence results simply from the depletion over time of the ground state population as an ever-increasing fraction of the absorber molecules is excited. The opposite situation, in which the absorption cross section(s) of the excited state(s) exceeds that of the ground state, gives rise to reverse saturable absorption (RSA), in which the absorption increases with input fluence. This enhancement of absorption reflects the increase in the population of the (more strongly absorbing) excited state(s) relative to that of the (less strongly absorbing) ground state. Both types of absorptive nonlinearity, saturable absorption as well as RSA, offer practical applications. For instance, saturable absorbers are commonly used as passive Q-switches in pulsed lasers. Materials exhibiting RSA, on the other hand, could be exploited in optical limiting applications such as

eye and sensor protection systems, which require high transmission of low-intensity radiation but high absorption at high input.

## 5.2 Self-focusing and self-defocusing

Self-focusing and defocusing can be explained by taking an example. Consider a material with negative refractive index $n_2$ and thickness less than Rayleigh length. When the sample is far from the focus, that is at the farfield, the intensity of the beam is not strong enough to cause any nonlinearity within the sample and the measured power on the detector remains approximately constant (Figure 5(a)). As the sample translates towards focus, the nonlinear absorption and refraction enhances and thus the sample acts like a variable lens. The sample will diverge the beam passing through it and a small amount of light will fall on the detector, resulting in increase in measured transmittance (Figure 5(b)). When the sample is at focus (Figure 5(c)), the lensing effect will be profound. However, the sample will not have any effect on the beam. As the sample moves away from the focus, the strength of the refraction decreases due to lower intensity. This results in decrease in measured transmittance (Figure 5(d)). Finally, when the sample reaches farfield, the intensity is weak to initiate nonlinearity, so the measured power on the detector remains constant (Figure 5(e)).

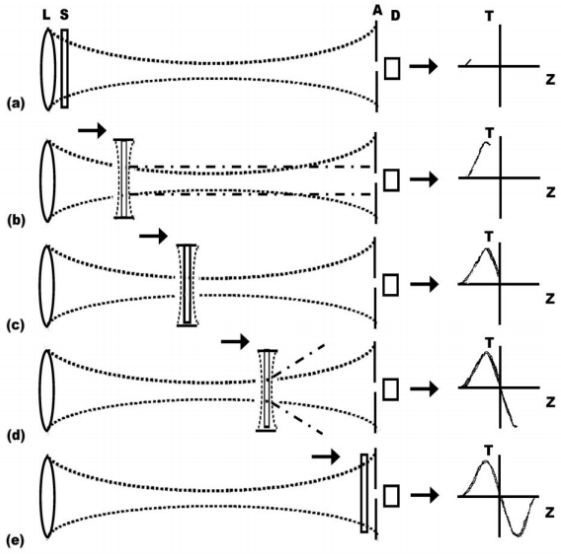


**Figure 5:** *Depicting the graphical z-scan experiment, used to measure the optical nonlinearities.*

# 6 Examples

Benzimidazole is a well known nonlinear optical material. Its SHG is about 4.5 times than that of the standard KDP. Our group is investigating the third order nonlinear optical properties of benzimidazole as well as its metal complexes. Metal complexes of benzimidazole shows better nonlinear effects than the parent ligand. For the better understanding and practical applicability of the things discussed in the earlier sections, here we provide the two examples z-scan analysis with their proto-type examples. Dichloro bis benzimidazole cobalt(II) (Co-BMZ) and Diaceto bis benzimidazole manganese (II) (Mn-BMZ) thinfilms were deposited by chemical bath deposition method. The third order nonlinear optical properties of the deposited thin films were studied by single beam z-scan technique at room temperature in open and closed aperture configurations. The absorptive and refractive coefficients were used to calculate the magnitude and sign of the real and imaginary part of third order nonlinear susceptibility. In this work, a 20 mW continuous wave diode laser of wavelength 650 nm was used as the source. A lens of focal length 15 cm was used to focus the beam on the sample and a digital power meter was used to record the variation in output intensity with respect to the sample position (Z). An aperture with linear transmittance of 40% was placed in front of the detector to record the CA scans and it was replaced by a convex lens to record the OA scans.

## 6.1 Co-BMZ thinfilms

In open aperture scan, the transmittance falls to a minimum at focus (z=0) for the Co-BMZ sample (Figure 6), thus indicating the nonlinear behaviour is due to reverse saturable absorption (RSA). In metal-organic materials the nonlinear optical process can be explained using a five level model diagram. Figure 7 shows two sets of energy levels $S_n$ and $T_n$ (n=1,2,3...) of a molecule corresponding to the singlet and triplet states respectively. When the sample was irradiated with a laser source, molecules in the ground state

($S_0$) get excited to the first electronic excited state ($S_1$), further they can make a transition to the first triplet state ($T_1$) by intersystem crossing (ISC) and usually the time scale for ISC is about 1 ns. Upon continuous laser irradiation, molecules in $S_1$ and $T_1$ can further get excited to $S_2$ and $T_2$ respectively. This type of transitions is referred as the excited state absorption (ESA). In low thresholds the transitions will be on nanosecond scale and the triplet-triplet ($T_1 \rightarrow T_2$) transition plays a dominant role in ESA process and ($S_1 \rightarrow S_2$) transition dominates at higher energies with picosecond time scale limits. Also, if ESA has greater excited state absorption cross section ($\sigma_{ex}$) than that of the ground state absorption cross section ($\sigma_0$) RSA takes place. On the other hand, if $\sigma_0$ is greater than $\sigma_{ex}$, saturable absorption (SA) will be observed. Observation of RSA in Co-BMZ films suggests that the ESA has greater excited state absorption cross section than that of the ground state absorption cross section and $T_1 \rightarrow T_2$ transition might dominate the RSA process due to the participation of metal ion in the electronic transition.

It can be seen from the CA curve Co-BMZ films show a valley-peak (V-P) type curve corresponds to the self focusing nature of the thin films. In CW regime, thermal effects dominate over other phenomena and variation in nonlinear refractive index of both the complexes can be attributed due to thermal nonlinearity. In the case of Co-BMZ films, laser heating in absorbing medium, induces a spatial distribution of temperature over the region and this inturn alters the laser beam passing through it. Thus the variation of refractive index is observed due to the strong phase distortion of the propagating beam.

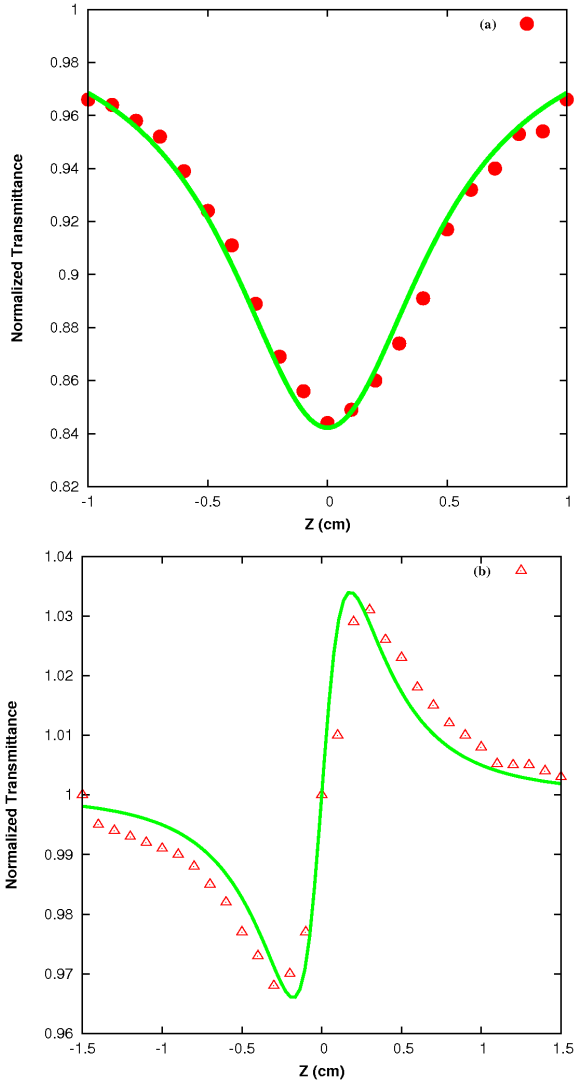


**Figure 6:** *Open and closed aperture curves of Co-BMZ films*

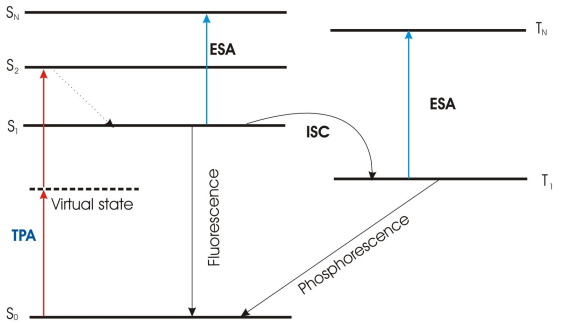


**Figure 7:** *Five level electronic transition model*

### 6.1.1 Optical Limiting (OL) Studies

The Co-BMZ thin film possess strong RSA phenomenon over the nonlinear refraction and they could be investigated for passive OL device applications. Optical limiters (OL) are the devices, which are transparent for the weak intense light but get opaque for high intense light. Optical limiting can be achieved by nonlinear optical process, either by nonlinear refraction or by nonlinear absorption. The experimental arrangement used to carry out the optical limiting studies is similar to the z-scan setup except a slight modification, such that a polarizer is placed in front of the sample in order to chop the input intensity on the sample. The obtained OL results are shown in Figure 8. At low irradiances the output inten-

sity increases with input intensity but at higher irradiances the medium starts to cease the output and hence the optical limiting is achieved.

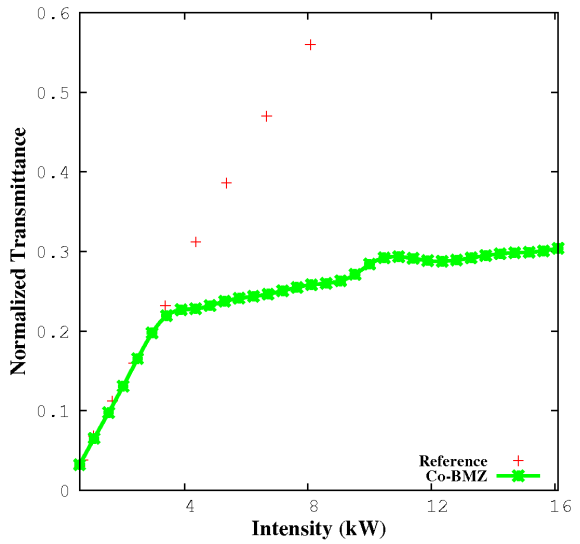


**Figure 8:** *Optical limiting of Co-BMZ thinfilms*

## 6.2 Mn-BMZ thinfilms

In the open aperture scan, the Mn-BMZ sample shows saturable absorption (Figure 9), indicationg that $\sigma_0$ is greater than $\sigma_{ex}$. The observation of SA in Mn-BMZ films suggests that the ESA has lower excited state absorption cross section than that of the ground state absorption cross section and $S_1 \rightarrow S_2$ transition process might dominate in the electronic transitions. Further, the sample shows self-focusing effect in the case of closed aperture scan.

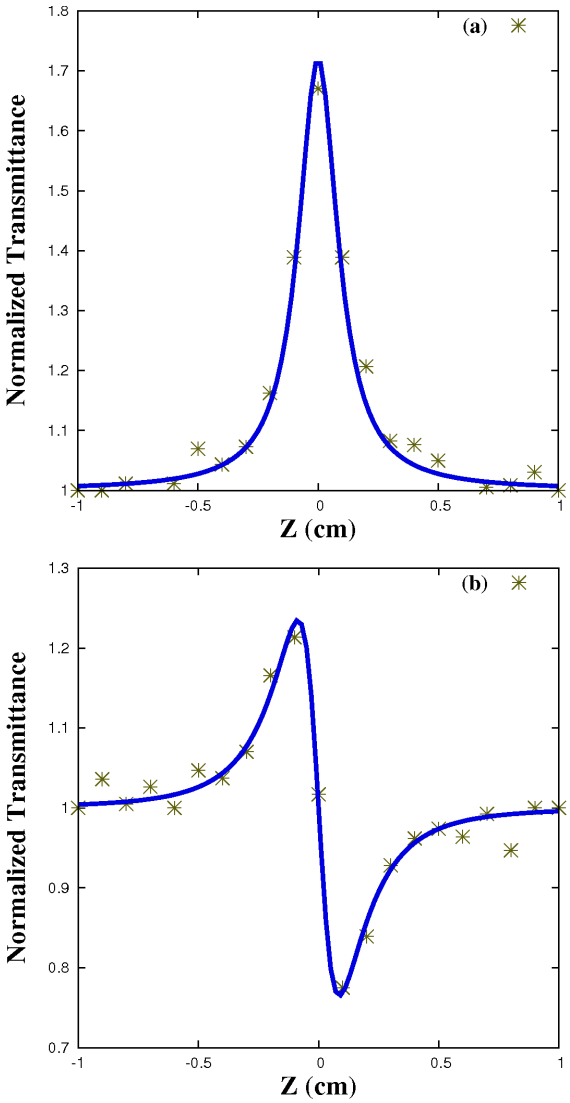


**Figure 9:** *Open and closed aperture curves of Mn-BMZ thinfilms*

### 6.2.1 Optical Switching

The thermal assisted nonlinear phenomena can be effectively utilized for optical switching applications. The inverted switching behavior of Mn-BMZ films was studied by using the setup shown in Figure 10.

The principle is that the population dynamics of the sample vary with respect to the intensity of the incident laser. i.e., a high power laser can produce a strong heating effect in a nonlinear medium than a low power laser and the corresponding variation in the excitation dynamics can alter the nonlinear effects. A CW diode laser of power 20 mW was used as the pump (writing) beam and a weak laser of power 1 mW was used as the probe (reading) beam. Both the lasers were operated at the wavelength of 650 nm. Since the sample possesses very low absorption in the 650 nm region, any observed variation can be attributed to the effect of thermal nonlinearity. The pump beam was passed through a mechanical chopper in order to obtain a square wave pattern (ON/OFF states). A lens of focal length 6 cm was used to focus the beams on the sample and the variation in probe beam with respect to the pump beam was measured using an oscilloscope. The obtained traces are shown in Figure 11. By properly adjusting the revolutions per minute (RPM) of the mechanical chopper, a frequency variation upto 1 kHz can be achieved. When the pump beam is in OFF state, the low power probe beam does not induce much

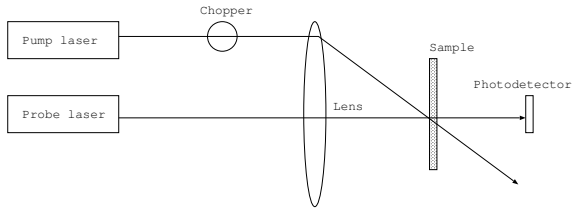


**Figure 10:** *Schematic of an optical switching setup*

effect in the nonlinear medium and it transmits through the sample as it is. But when the pump beam is in ON state, the intensity of the beam induces the thermal assisted nonlinear effects in the medium which leads to the saturation of population in the excited state and correspondingly a low state was obtained as output. This corresponds to the inverted switching behavior of NOT gate, analogous to electronics.

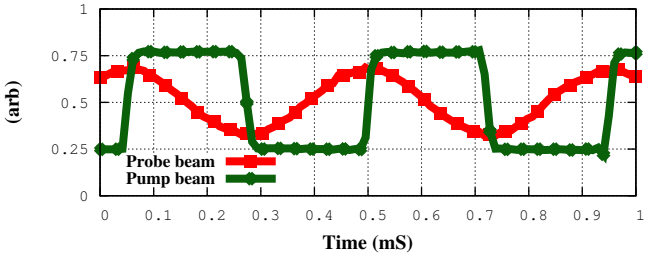


**Figure 11:** *Demonstration of optical inverter switch in Mn-BMZ film*

# 7 Summary

Nonlinear optics is one of the promising fields with variety of practical as well as future applications. Two primary areas of interest in nonlinear optics is second and third order nonlinearities. Z-scan is one of the potential tools available to analyse third order optical nonlinearity. It is very simple to construct, experiment and record data using z-scan. There are two configurations in this technique, such as open and closed apertures. Depending on the type of configuration, nonlinear apsorptive ($n_2$) and refractive ($\beta$) coefficients can be evaluated. The third order nonlinear susceptibility can be calculated from suitable relations by using $n_2$ and $\beta$. Further, depending upon the major contribution from nonlinear absorptive or refractive coefficients, the samples can be utilized either for optical limiting or optical switching. Two of our previous studies were discussed in this review with the demonstration of proto-types. In conclusion, this technique can be effectively used to analyse the potentiality of any kind of samples such as crystal, thin film or liquid, which is intent to be used for third order nonlinear optical applications.

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